Exploring the Determinants of Energy Demand in Malaysia: Empirical Analysis

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Abstract

This study delves into Malaysia's energy utilization dynamics, an emerging economy in the ASEAN region. Energy consumption in Malaysia has surged alongside rising per capita income, notably during the shift from a primary-sector-driven economy to an industrialized and urbanized one since 1970. Sustainable resource management, particularly in the energy sector, is crucial for achieving long-term sustainability goals. Using Bound Estimation and annual data from 1985 to 2020, this research employs a comprehensive systems approach, considering economic growth, foreign direct investment, urbanization, governance, and innovation to assess energy determinants in Malaysia. The results highlight economic growth, foreign direct investment, rapid urbanization, and technological advancement as the primary drivers of increased energy usage. Additionally, corruption indirectly influences energy consumption. These findings underscore the necessity for tailored energy policies, with a strong emphasis on promoting alternative energy sources to align with the nation's development goals. Understanding the root causes of Malaysia's escalating energy consumption equips policymakers with valuable insights to formulate sustainable strategies, ensuring steady economic growth while addressing energy-related challenges.

Keyword: Technology advancement, foreign direct investment, energy consumption, Bound estimation

INTRODUCTION

Energy is one of the most important aspects to maintain social operation. It not only affects citizens' daily lives, but it is also a major driving factor in the development of an economy. Energy consumption has expanded considerably in recent years as a result of the fast growth of the population and economy (Zhongye, Xin and Yifei, 2023).

Malaysia, as one of the ASEAN region's fastest-growing economies, has seen its energy usage rise in tandem with increasing per capita income. Prior to 1970, when Malaysia was in its early phases of industrialization, energy consumption was relatively low because the primary sector dominated economic activity. However, as the secondary sector progressively replaced the primary sector, energy usage increased in tandem with industrialization and urbanization (Chong et al., 2015).

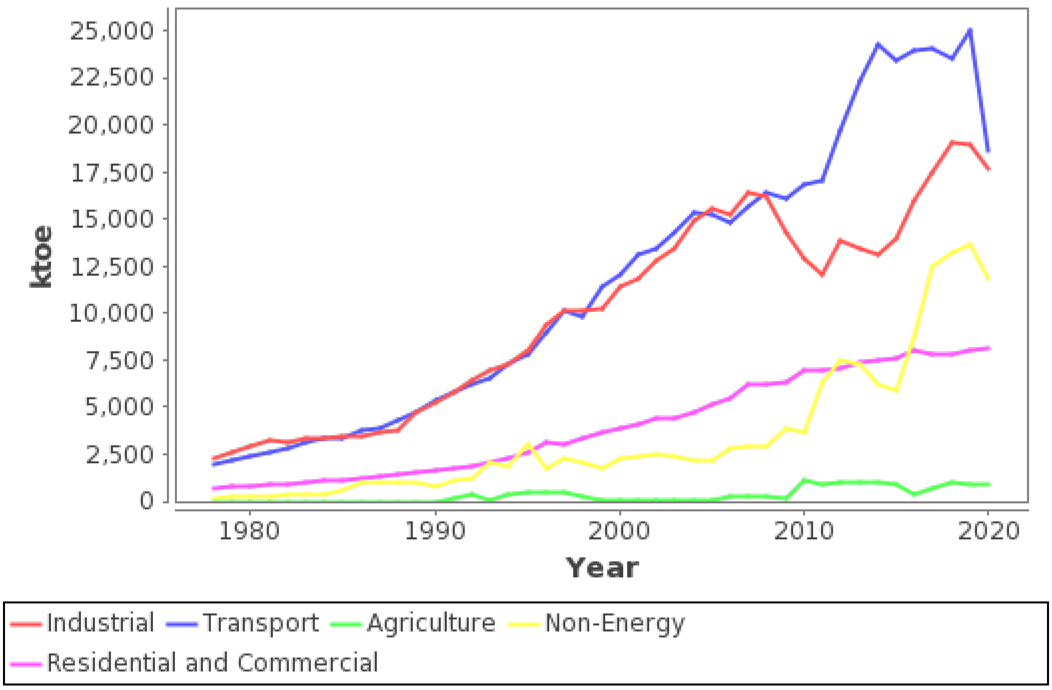

Figure 1. Composition of Malaysian final energy demand by sector. Source: Malaysia Energy Information Hub.

The pattern of energy use differed by economic sector as can be seen in Figure 1. In 1980, industry used approximately half of energy. Industrial energy use decreased once manufacturing moved to services. Population expansion drove energy demand. Income and energy prices affect energy use. Energy consumption rises when an economy shifts toward energy-intensive industry. Heavy industries like petroleum refining, metals, cement, and chemicals need more energy as industrialization progresses. Most developed nations consume more energy per person. Since the 1970s, population, agriculture, industry, social inequality, natural resources, particularly energy, and pollution have been identified as global eco-crisis causes. Since then, various experts have studied energy use and economic or environmental factors (Wang, Chen and Kubota, 2016). Furthermore, it is generally accepted around the globe that reducing energy usage is necessary to lessen the impact of climate change. A set of 17 sustainable development goals were produced by the United Nations as part of its sustainable development strategy for 2015, named the 2030 Agenda (United Nations, 2015). Number seven in this set of goals is refereeing directly to the energy sector: “Affordable and clean energy”. Managing resources as a whole is a critical aspect of reaching sustainability goals, and the energy sector is a big piece of this puzzle. The Industrial Revolution happened in the background of the current eco-crisis, which is the damage to the environment caused by overusing energy resources and making climate change worse. Still, we have to ask: What are the most important things that affect the energy sector? Where should we put our attention if we want to build a sustainable energy industry? Other experts also help figure out the answers to these queries such as Zhao et.al, (2018), Ntanos et.al., (2018), Caraiani, Lungu and Dascalu, (2015), Kasman and Duman, (2015) that studying the relationship between energy consumption and gross domestic product. However, some of the results are inconclusive or mixed and they heavily depend on the indicators considered and the methodology chosen. Therefore, the need for retesting some of the already analyzed variables is obvious, as it is the inclusion of new indicators and indices of the social, economic, and environmental system. In this case, this study aims to assess the energy determinants at Malaysia through a holistic approach of the system (including all the areas: economic growth, foreign direct investment, urbanization, governance and innovation) in order to identify critical points (some not yet explored) which influence the sustainability of the energy sector.

Foreign direct investment (FDI) is often advantageous to major infrastructure industries, including energy-related services. Some researchers have highlighted the relevance of FDI in financing energy-efficient alternatives to minimize fossil fuel usage (Kuo, 2014). Increased lending encourages the purchase of energy-consuming items (Chang, 2015). As the demand for energy increases and the availability of natural resources decreases, it has been hypothesized that the price of energy will eventually rise (Hicks, 1963). A higher energy price will induce the development of more energy-efficient technology. Jiang and Ji (2016) claimed that technological advancement has an impact on energy use. Their empirical study demonstrated that trade-induced technical development reduced China's energy intensity by allowing more advanced equipment to be imported. As a result, technological innovation is vital for saving energy. Depending on how the power is generated, electric vehicles (EVs) can be substantially cleaner than petroleum-fueled internal combustion engines. However, in most nations, measuring technical advancement is challenging, making it impossible to assess the influence of technology progress on energy demand. As a result, numerous research employed patent applications as a proxy (Sohag et al., 2015, Yan, Shi and Yang, 2018). A study by Yan, Shi and Yang (2018) found that technological development improved energy productivity. Considering this finding, energy consumption should have fallen in proportion to the degree of technological improvement. However, energy demand has increased in most countries, a phenomenon known as the “rebound effect”.

Therefore, this study aims to examine the short- term and long-term relationship between selected variables and energy used in Malaysia using Bound Estimation. By identifying the underlying causes of increasing energy used in Malaysia, policymakers can develop sustainable initiatives to address the issue and maintain stable economic growth.

The following section focuses on the literature review. Next, section 3 explains the methodology of this study, followed by analysis and discussion in Section 4. The last section highlights the conclusion and policy recommendations.

LITERATURE REVIEW

DV: Energy Use impact climate change

Energy is essential for the majority of societal activities today. Since energy plays a pivotal role as the most significant resource for developing and developed countries, the demand for reliable and affordable energy is rapidly increasing. The primary drivers of the world’s rising energy demand are population growth and economic development (Begum et al., 2015). It can be beneficial and even life-saving in many aspects of human society whether it is direct or indirect activities, including transportation, building conditioning, manufacturing and the business sector, (Aldhshan et al., 2021). Energy sources come in a variety of forms and are divided into non-renewable and renewable sources. Non-renewable energy sources include coal, natural gas, uranium, and fossil fuels. On the other hand, renewable energy sources include hydropower, geothermal energy, solar energy, tide/wave/ocean energy, wind energy, solid biofuels, biogas, and liquid biofuels (Solarz et al., 2022).

Since the last decade, the demand for energy has increased and according to The World Energy Outlook 2018 reports, show that 2.3% increase in global energy demand. 70% of the increase in global energy demand was accounted for by the United States, China, and India (IEA, 2018), while other countries in ASEAN, the Middle East and North Africa (MENA) are also anticipated to rise. More than 80% of the world's total energy consumption is accounted for through non-renewable sources, such as fossil fuels (Aldhshan et al., 2021). Unfortunately, non-renewable energy is the main source of carbon dioxide (CO2). This drives environmental deterioration, major leads of climate change and causes greenhouse gases (Halder et al., 2015). Farabi et al. (2019) stated that energy use is the main contributor to many of Earth's worst environmental issues, including climate change, air pollution, global warming, and greenhouse gases.

Based on the Malaysia Census 2020 report released by The Department of Statistics Malaysia (2020), the primary energy supply in Malaysia in 2018 amounted to 99,873 kilotons of oil equivalent (ktoe). Out of this total, a significant portion of 92,627 ktoe was derived from fossil fuels, while renewable sources accounted for only 7,226 ktoe. This highlights the heavy reliance on fossil fuels for the country's energy needs. Besides that, according to a report from the US Energy Information Administration (2021), natural gas and petroleum and other liquids are the primary energy sources used in Malaysia in 2019, comprising approximately 37% and 36% of the energy mix, respectively, while coal contributes to around 21% of the country's energy consumption and only 6% of overall energy usage is from renewable sources. These statistics illustrate how infrequently renewable energy is used and how heavily the country's energy industry relies on fossil fuels.

Thus, air pollution has become a major concern for environmental issues in Malaysia, due to a number of causes such as the burning of the burning of natural gas, petroleum, coal, lignite, and animal and agricultural wastes (Suhaimi et al., 2020). About 118 million tons of CO2 were emitted in Malaysia in 2006, which indicates that the average person's CO2 emissions were 7.2 tons (Shafie et al., 2011). The percentage is still dramatically rising, and according to research published by World Data Atlas, it reached roughly 248.8 million tons in 2019 (Aldhshan et al., 2021). Besides, The International Energy Agency (IEA) demonstrated in 2015 that energy-burning activities, particularly those in the transport sector, are the main source of CO2 emissions in Malaysia (IEA, 2018).

Numerous studies from the past have shown that using fossil fuels has negative effects on the environment and increases carbon emissions. These effects have been observed in both developing and developed countries (Alola et al., 2019; Destek et al., 2020; Sharif et al., 2020). Additionally, using fossil fuels not only increases greenhouse gas emissions but also decreases the availability of non-renewable resources, which are becoming scarcer as a consequence of increased economic activity and development. Due to the exhaustion of natural resources and a concerning rise in air pollution leading to changes in global climate and temperature (Wang et al., 2023). Thus, the global need to reduce CO2 emissions has grown (Ma et al., 2019).

While energy is widely acknowledged as a key factor in driving economic growth and supporting a variety of economic activities (Shahbaz et al., 2017), the challenges brought on by the current climate crisis have been made worse by our excessive dependence on fossil fuels and other non-renewable energy sources (Saudi et al., 2018). In response, plenty of countries including Malaysia have started looking for alternative energy sources to reduce their dependency on fossil fuels for the production of energy (Lin et al., 2018). Also, realizing the crucial role that energy plays as a basic component for both economic and social advancement, the Malaysian government continually reviews and revises its energy policy in order to ensure the long-term security and stability of its energy supply (Mohamed et al., 2006). The policies that Malaysia had established in order to foster the use of renewable energy sources are the Five Fuel Diversification Act in 1999, the Renewable Energy Act in 2011 and the 11th Malaysia Plan (2016-2020), which includes "pursuing green growth for sustainability and resilience" as one of its strategic thrusts to foster green technology (Lin et al., 2018). This can be supported by other research (Sharif et al., 2019; Destek et al., 2020; Usman et al., 2021), which has demonstrated that the usage of renewable energy reduces the environmental impact because these energy sources recover and do not produce pollutants.

Considering these findings, it is clear that switching to renewable energy is essential for reducing the negative effects of fossil fuel usage on the environment and tackling these issues. Therefore, despite its heavy reliance on non-renewable energy sources like fossil fuel and natural gas as a source of energy, Malaysia needs to move quickly towards renewable energy because these sources will eventually run out, as well as harm the environment and contribute to the problem of climate change.

(1) LNFDI - Foreign Direct Investment

Foreign direct investment (FDI) can be known as multinational businesses (MNEs) that often transmit knowledge, technology, management techniques, and systems to their host countries (Doytch et al., 2016). FDI might have both good and negative effects on how much energy is utilized, which could affect climate change. A study by Baloch et al. (2019) examined the relationship between financial development and FDI and ecological footprint in 59 BRI countries between 1990 and 2016 and discovered that these factors contribute to pollution and environmental deterioration. Also as noted by Chandran et al. (2013), FDI may encourage greater economic growth but may worsen environmental problems. There are also several developing countries purposely attracting foreign companies by adopting environmental regulations in order to emphasize economic and increasing FDI while neglecting environmental energy efficiency which leads to worsening environmental issues (Yao et al., 2019). Furthermore, a study by Saqib et al. (2023) discovered that developing countries are positively impacted by FDI when it comes to pollution and environmental degradation (pollution haven hypothesis), and it is widely acknowledged that some of these FDI inflows were drawn to developing countries because of their weak environmental laws.

In contrast, Solarin et al. (2018) discovered most developed countries are negatively impacted by FDI when it comes to carbon emissions and environmental degradation (pollution halo hypothesis) due to their strict environmental regulations. This halo hypothesis has also been supported by Shahbaz et al. (2016) study that mentions FDI caused a reduction in pollution and environmental deterioration. But, the greatest net inflows of FDI were drawn by Russia and Turkey, which also have the greatest levels of technological advancement and financial growth, and had suffer from significant environmental degradation (Wang et al., 2023). As stated by Adam (2009), there are two ways that FDI may improve environmental quality, through the augmentation effect and the efficiency effect. The augmentation effect is connected to the potential for higher total investment, which may support societal advancements and economic growth. On the other hand, the efficiency effect relates to the positive externalities connected to FDI flows, such as innovations in technology, marketing knowledge, and managerial skills. These elements can increase energy efficiency and industrial competitiveness (Adam et al., 2018; Stavropoulos et al., 2018).

Energy-saving technology may be delivered through FDI to host countries, therefore reducing the demand for non-renewable energy. This enhances the country's capacity for sustainable development (Perkins et al., 2008). Wang et al. (2023) indicate that FDI contributes significantly to the spread of technology in developing countries. By encouraging the use of cleaner technologies and more effective management practices, this technology transfer through FDI has the potential to help reduce the consumption of non-renewable resources and environmental issues. The majority of ASEAN countries, including Malaysia have received more advanced, cleaner technology from developed countries that have come for FDI (Chung, 2014).

In conclusion, as FDI has both good and negative consequences, the relationship between FDI and energy usage that may have an influence on climate change is complicated. FDI may benefit the countries that receive it by bringing knowledge, technology, and management practices, which may improve environmental and energy quality. However, FDI may also result in pollution and the deterioration of the ecosystem. In the case of Malaysia, it's crucial to properly regulate FDI to make sure that it encourages the use of energy sources and has the least possible detrimental effects on the environment.

(2) LNURB – Urbanisation

As defined by Shahbaz et al. (2017), urbanisation is the process of concentrating large numbers of permanent residents in relatively small areas to form densely populated metropolises. In other words, urbanisation can be described as the migration of people from rural or agricultural areas to urban or non-agricultural areas. Malaysia has increased its urbanisation over the past ten years and is currently considered one of the most urbanised nations in East Asia. The population increased in urban areas from 66% in 2004 to 74% in 2014, and by 2020, a greater percentage of people, approximately 77%, would live there (Udemba et.al., 2022). It is expected that the growing urban population in those areas would have significant consequences on energy usage. Data from the IEEJ (2019) can be supported the statement, which predicts a rise in energy consumption as a result of the population and economic growth in India, ASEAN, the Middle East, and North Africa. This trend is expected to continue as people migrate from rural areas to urban areas due to greater economic prospects, better health care, and employment opportunities.

However, the majority of existing literature on the subject has found empirical evidence supporting a correlation between urbanisation and energy use impact climate change. Udemba (2022) stated that urbanisation may have a negative effect on the economy and the environment, causing a number of problems such as growing unemployment, higher energy use, climate change, and health problems. This point of view is in line with research by Khan (2021), who found that the migration of people from rural to urban areas has increased industrial activity, transportation, and consumption by households, which has rise the energy demand and worsened Malaysia's environmental conditions.

Moreover, in a study conducted by Jones (2007), who examined data from 59 countries that were developing in 1980, it was shown that urbanisation could result in greater energy use because of transportation and economic activity. Shahbaz et al. (2015) also found that urban population development has a negative impact on the environment, leads to rising expenses, and creates social inequalities. Due to the increasing demand for housing, increased investment and industrialisation, as well as other contributing factors, energy consumption is expected to rise as cities grow. Besides, Ahmad et al. (2016) study found that since 1970s, the urban areas in Malaysia have seen a significant increase in temperature due to fast development. Also, according to research by Han et al. (2017), industries other than agriculture, such as the building sector, businesses, and factories, have the most effects on rising emissions and energy use. Poorly planned building constructions may have a direct impact on soil temperature as buildings were indirect heat source for surrounding soil (Rajamoorthy et al. 2018).

Nevertheless, different studies have discovered a negative relationship between urbanisation and energy use. Lafrance (1999) found that Canada's most urbanised areas had low energy usage rates per capita. Similarly, to this, Pachauri (2008) discovered that the use of inefficient solid fuels, which accounted for more than 85% of residential use in China and India, caused the use of energy in rural areas to be higher than in urban areas. Additionally, Ke et al. (2015) conducted a study using the STIRPAT model to analyze data from 73 countries and discovered that the relationship between urbanisation and energy use is not universal. The findings demonstrated that, depending on the country's economic growth level, urbanisation has various effects on energy usage. Particularly, urbanisation does not always lead to a rise in energy usage in upper-middle-income and low-income countries, but it does in lower-middle-income countries (Ke et al., 2015).

Most of existing literature generally agree a positive correlation between urbanisation and its significant influences on energy use and the environment. Due to increased industrial activity, transportation needs, and household consumption, Malaysia's growing urban population is predicted to have a notable impact on energy use, resulting to higher energy demands and environmental deterioration. To address these concerns, it is crucial to prioritise sustainable urban design, promote energy-saving practices, and make investments in renewable energy sources. By putting these steps in place, Malaysia can reduce the negative effects of urbanisation on energy use and help create a future that is more ecologically friendly and sustainable.

(3) LNCOR - Governance

Looking at the determinant of energy used in the context of Malaysia, the government plays a vital role as the main purpose of a government is to provide a system of governance that promotes the welfare of its citizens, protects their rights, maintains order and security, and manages the resources and infrastructure of the country. The government will influence the energy consumption in a country as they promote the energy policies which can influence community behavior towards energy consumption (Chang, 2018).

Government ideology is a factor that may have an impact on energy and the environmental policies in the country. According to Chang (2018), governments with left wing parties are commonly associated with higher energy efficiency compared to the right-wing parties. Left-wing governments typically prioritize the transition to renewable energy sources such as solar, wind, hydroelectric, and geothermal power. They may promote the development of renewable energy technologies to reduce dependency on fossil fuels and counter climate change (Cadoret & Padovano, 2016; Neumayer, 2006; Karlstrøm & Rygh Aug, n.d) .

On the other hand, Right-wing government has found significant negative effects in supporting energy efficiency and reducing pollution (Lockwood & Lockwood, 2022). According to the study, right-wing governments are promoting the energy deregulation market and the attention of the government seems to have a positive effect on market deregulation (Cadoret & Padovano, 2016). As mentioned about deregulation, this party prioritizes the usage and development of non-renewable energy which uses fossil fuels, such as coal, oil, and natural gas. It also supports policies that promote domestic fossil fuel production and exploration, including deregulation and tax incentives for the fossil fuel industry (Czarnek, n.d.).

In sum, it is important to note that the ideology may affect the energy consumption for the country and economic growth. Right-wings parties will focus on prioritization of business and boost economic growth, however left-wings parties will work for environmental protection. These principles serve as a general guide, but the actual implementation and emphasis on various aspects can differ based on national priorities, available resources, and the political landscape of the country.

(4) LNINV - Innovation

As mentioned above, the government plays an important role in determining the energy used in the context of Malaysia and technological Innovations is necessary for better energy consumption. Innovation is important for businesses and when utilized well it can be a process, strategy, and management technique. Innovation is the process of generating and integrating new ideas to connect the actual knowledge and current knowledge to solve problems in the future. It frequently follows technical advances and has significance to the global economy (Baskaran & Mehta, 2016; Stenberg, n.d.).

Technological innovation is needed to enhance energy efficiency and reduce energy consumption in the industrial sector, which in the end reduces emissions. Technological innovation can positively or negatively influence energy consumption. As it may increase energy consumption in the economy through rebound effects which means that efficiency increase often reduces product and service costs (Harchaoui & Chatzimpiros, 2018). Li & Solaymani (2021), confirmed that technological innovation has a positive impact on energy efficiency as China has improved significantly in terms of energy efficiency. It indicates more than 10 EJ of energy were saved in China in 2017 because of improvements in energy efficiency in industry, the service sector, and the housing sector (Wang & Wang, 2020).

Furthermore, even if technological innovation does not directly reduce energy consumption, it will improve energy efficiency with developing energy structure (Jin, 2018). As proven, the study shows that even though the Chinese had an increase in energy consumption, it also improved energy efficiency and energy consumption structure.

However, according to Murad (2019), technological innovation has negatively influenced energy consumption and caused further energy consumption. This is because higher economic growth requires more energy supply for the country. In conclusion, the government needs to enact energy use policies and control prices as well as tax imposition in the country. This action leads to enhance energy efficiency with reducing energy consumption and protecting the environment from pollution.

(5) LNGDP - Economic Growth

The high demand for energy is one of the factors in boosting the economic growth. Economic growth can be defined as the outcome of growth in inputs and increases in the productivity of the inputs (Ozcan, 2020). Improvements in productivity will result in economic growth. Therefore, increasing or using energy (renewable and non-renewable) more effectively is necessary for economic growth. But, the great energy output might have a negative influence on the environment.

To make an economic expansion, energy consumption needs to be driven at full capacity to achieve efficiency in economic growth. According to Rahman & Velayutham (2020), it indicates that both types of energy consumption (renewable and non-renewable) is influenced positively and it affects positively on economic growth. This study has been made in South Asia countries which is Pakistan, India, Nepal, Sri Lanka, and Bangladesh. However, renewable energy consumption is stronger than non-renewable energy. Furthermore, there are a lot of studies that claim energy consumption leads to economic growth especially in non-renewable energy (Chen, 2020; Ozcan, 2020; Rahman & Velayutham, 2020; Reddy, 2020; Tang, 2016; Ang, 2007).

However, in terms of renewable energy consumption, the study shows that renewable energy does not contribute to the economic growth in developing countries (Chen, 2020). This is because of the usage of renewable energy below a given threshold level and it negatively affects economic growth. But they can avoid negative economic growth by increasing their renewable energy growth and surpassing the threshold level of renewable energy. This result could be positive if it tests the threshold model in OECD countries. Moreover, the study by (Reddy, 2020) indicates that renewable energy has a negative impact on economic growth in 9 countries which are Belgium, Italy, Israel, Morocco, Romania, Portugal, South Africa, Thailand, and the United States. This is because of the reduction in renewable energy output and the energy conservative policies that implemented not achieving economic output.

Thus, those countries and developing countries need to increase investment into renewable energy to surpass the threshold level and increase energy output. Actually, there is a country already investing in renewable energy to expend economic growth which according to Reddy (2020), the Turkish government imposed the National Renewable Energy Action Plan (NREAP) to attain 30% of its entire renewable energy installed capacity by 2023. Lastly, to meet the objective, the whole country must invest more capital in the development of renewable energy efficiency and promote the use of renewable energy by offering a variety of incentives, public-private partnership investments, and grants.

3. Methodology:

3.1 Theoretical Framework:

In the realm of energy economics, the concept of standard energy demand is intrinsically tied to the dynamics of income and energy prices (Nicholson and Snyder, 2021; Samuelson, 1986; Varian, 1996). This foundational relationship has been extensively explored and substantiated in various studies (Shohag et al.2015, Hussain et al.2020, Alam and Murad, 2020). When we contemplate the equilibrium point in the market, wherein energy demand aligns perfectly with energy consumption, a robust framework emerges for expressing the energy demand function. This function finds its roots in the classic Marshallian demand theory (Friedman, 1949), particularly when considered within the context of a specific moment in time, denoted as "t." The Marshallian demand theory, pioneered by the eminent economist Alfred Marshall, offers invaluable insights into the decision-making processes of consumers regarding their expenditures on goods and services (Friedman, 1949). In our energy-focused paradigm, it serves as a versatile tool for comprehending how individuals, businesses, or even entire economies navigate the intricate interplay of income and energy prices to determine their energy consumption patterns (Shohag et al.2015). Expanding upon this foundation, let's delve into the intricate relationship between income and energy demand. As individuals or entities experience an uptick in income, they typically find themselves empowered with greater financial resources. This financial capability, in turn, often translates into an increased appetite for energy-intensive activities and services (Santika et al.2020). Consequently, the demand for energy rises in tandem with the income level, reflecting the positive correlation between these variables. Conversely, the influence of energy prices on energy demand is equally important. When energy prices surge, consumers often face budgetary constraints and are compelled to be more judicious in their energy consumption (Torriti, 2017). This leads to a reduction in energy demand as individuals and entities seek to optimize their energy usage and minimize costs. Hence, energy prices exhibit an inverse relationship with energy demand, with higher prices generally resulting in reduced consumption. The energy demand equations can be written as follows:

$$E_{Dt} = f(Y_t, P_{et}) \qquad (1)$$

In equation (1), $E_{Dt}, Y_t, and\ P_{et}$ stand for, respectively, energy demand, income, and the cost of energy at time t.

This study considers the influence of FDI, urbanization, corruption, and technological innovation on energy use, as discussed in the introduction section.

$$\mathrm{E_{Dt}} = \mathrm{f(Y_t, P_{et}, FDI_t, URB_t, COR_t, INV_t)} \qquad (2)$$

In Equation (2) FDI_t denotes Foreign Direct Investment, URB_t for urbanization, COR_t for corruption, and INV_t for technological innovation.

In accordance with the conventional Marshallian demand framework, the income elasticity of energy is depicted as positively related, expressed as $\frac{\partial E_t/\partial Y_t}{E_t/Y_t} = \varepsilon_{Ye} > 0$, where E_t represents energy demand and Y_t corresponds to income. This implies that as income (Y_t) increases, the energy demand (E_t) also rises, signifying the propensity of individuals or entities to consume more energy as they become more financially capable. Conversely, the price elasticity of energy within this framework displays a negative association, denoted as $\frac{\partial E_t/\partial P_t}{E_t/P_t} = \varepsilon_{Pe} < 0$, where E_t stands for energy demand, and P_{et} signifies energy prices. In this context, a negative value suggests that as energy prices (P_{et}) increase, energy demand (E_t) is anticipated to decrease. This reflects the typical behavior observed in response to higher energy costs, where consumers tend to be more cautious and efficient in their energy consumption.

However, it's noteworthy that this particular study deviates from the standard analysis by not treating energy prices as independent variables. This decision stems from the unique economic circumstances in Malaysia, where energy prices are heavily subsidized (Shohag et al.2015). In the Malaysian context, government policies and subsidies have a substantial impact, maintaining energy prices at artificially low levels. Consequently, the usual price-demand relationship found in other markets doesn't apply directly. This departure underscores the distinct nature of Malaysia's energy market, where energy prices are regulated and don't fluctuate freely based on supply and demand dynamics. As a result, the standard price elasticity of energy, which typically indicates how price changes affect energy demand, doesn't hold in the same way. In this specific context, the impact of energy prices on energy demand is somewhat muted, and other factors may have a more pronounced influence on energy consumption patterns.

Grossman and Helpman (1991) found that technological innovation plays a significant role in promoting economic growth through increased factor productivity and improved energy efficiency (Ang, 2011). This study examines the impact of technological innovation on energy consumption, assuming that all other factors remain constant.

This study quantifies technological innovation by examining the number of patent applications, using the methodology outlined in Madsen et al. (2010). Hence, it can be inferred that the parameter representing the partial change in energy consumption resulting from technological changes should have a negative value, denoted as, $\frac{\partial E_t}{\partial INV_t} = d_e < 0$. This study includes trade openness as a variable in the empirical model. As mentioned in the introduction, trade openness can have both positive and negative effects on energy consumption, represented by the equation $\frac{\partial E_t}{\partial FDI_t} = FDI_e \mp$ .The negative elasticity of trade suggests that trade facilitates the transfer of technologies from more technologically advanced economies to the local economy, resulting in a decrease in energy consumption. Conversely, the positive trade elasticity with respect to energy use suggests that trade leads to an increase in energy consumption. Hence, the energy demand function for Malaysia can be expressed as an empirical model in the following manner:

$$\mathrm{ENC} = \mathrm{f}(GDP_t, \mathrm{FDI_t}, \mathrm{URB_t}, \mathrm{COR_t}, \mathrm{INV_t}) \quad (3)$$

Where, ENC used to denote energy use.

The Econometric version of Equation (3) can be written as:

$$\mathrm{ENC_t} = \beta_0 + \beta_1 GDP_t + \beta_2 \mathrm{FDI_t} + \beta_3\ \mathrm{URB_t} + \beta_4\ \mathrm{COR_t} + \beta_5\ \mathrm{INV_t} \quad (4)$$

In Equation (4), β_1 to β used as a slope coefficients of explanatory variables.

We transformed all variables into logarithmic form in Equation (5). Logarithmic variables are a valuable tool in data analysis and modeling. They help make data more amenable to statistical techniques, improve interpretability, and address issues related to non-linearity, heteroscedasticity, and outliers. However, it's important to carefully consider the implications of logarithmic transformations, such as how they affect the interpretation of coefficients and how to communicate results effectively when working with log-transformed data.

$$\mathrm{LENC_t} = \beta_0 + \beta_1 LGDP_t + \beta_2 \mathrm{LFDI_t} + \beta_3\ \mathrm{LURB_t} + \beta_4\ \mathrm{LCOR_t} + \beta_5\ \mathrm{LINV_t} \quad (5)$$

3.2 Data and Description:

Table 1 provides an overview of the data sources and their corresponding descriptions utilized in this research endeavor. The analysis encompasses annual data series from Malaysia spanning the timeframe between 1985 and 2020. Within this study, Energy Use serves as the dependent variable, while the independent variables consist of Foreign Direct Investment, GDP per capita, Technological Innovation, Urbanization, and Corruption.

Table 01: Description and Sources of Variables.

Short Name	Variables Name	Details	Sources
LnEN	Energy Used	Energy used (renewable + nonrenewable) in the context of Malaysia	
LnGDP	Economic Growth		
LnFDI	Foreign direct Investment		
LnURB	Urbanisation		
LnCOR	corruption	level of corruption	
LnINV	Innovation	total patent per capita	

3.3 Empirical Framework and Method of Estimation

This research employs a range of inferential data analysis techniques to extract meaningful insights. The analytical method includes the ARDL bound test, unit root test, and several diagnostic test which collectively contribute to a comprehensive diagnostic assessment of the dataset. These methodologies enable us to explore relationships, detect cointegration, and assess the stationarity of the data, enhancing the rigor and depth of our analytical approach.

3.3.1 Unit root test

In econometrics and time series analysis, the unit root test is a statistical procedure used to determine whether a time series dataset follows a stationary or non-stationary process. A stationary process in time series analysis is one whose statistical properties, such as mean, variance, and autocorrelation, remain constant over time. Non-stationary processes, on the other hand, display statistical properties that vary over time, typically as a result of trends or other structural changes (Rihan and Voumik,2022; Ridwan, 2023). The unit root test is an indispensable method for determining the stationarity of time series data, and it has numerous applications in statistical analysis. By determining whether a time series has a unit root, analysts are able to make informed decisions regarding differencing and model selection, thereby ensuring the application of appropriate statistical methods (Voumik and Ridwan,2023). This helps prevent false results, improves the accuracy of forecasts, informs economic and financial policy decisions, and ultimately fosters more robust and reliable insights into the data's underlying dynamics and trends (Pattak et al.2023). Numerous studies recommend conducting multiple stationarity tests because the efficiency of these tests varies with sample size when determining the classification of series integration. This study employed Augmented Dickey Fuller (Dickey and Fuller, 1979) unit root test developed by Dickey and Fuller (1979) and Philips Perron unit root test established by Philips and Perron (1998) to check stationarity.

3.3.2 Autoregressive Distributive Lag Model (ARDL)

The investigation utilized the ARDL model, established by Pesaran et al. (2001), as an efficient estimating tool to reveal both short- and long-term interactions among the model's parameters. The Autoregressive Distributed Lag (ARDL) method holds a distinct advantage over other cointegration approaches due to its flexibility and versatility in analyzing relationships between non-stationary time series variables. Unlike traditional cointegration methods like the Engle-Granger two-step procedure or Johansen cointegration tests, ARDL accommodates cases where the variables have different orders of integration, making it applicable to a wider range of economic and financial datasets. Furthermore, ARDL offers several key benefits. It allows for small sample sizes, making it robust even when dealing with limited data observations, which is particularly advantageous in empirical research. ARDL also facilitates the incorporation of lag structures, enabling the modeling of dynamic relationships between variables. Moreover, it provides an error correction mechanism, which captures both short-term dynamics and long-run equilibrium relationships. This feature is particularly valuable for studying economic phenomena where short-term adjustments play a crucial role in restoring equilibrium. Therefore, ARDL's ability to handle mixed orders of integration, accommodate small sample sizes, model lag structures, and incorporate error correction mechanisms makes it a superior choice for analyzing cointegration in time series data, enhancing its suitability for a wide array of empirical studies and econometric applications.

. Equation 6 illustrates the ARDL limits test:

$$\Delta LENC_t = \text{ꝟ}_0 + \pi_1 \mathrm{LENC}_{\mathrm{t}-1} + \pi_2 LGDP_{t-1} + \pi_3 LFDI_{t-1} + \pi_4 LURB_{t-1} + \pi_5 LCOR_{t-1} + \pi_6 LINV_{t-1} + \sum_{i=1}^{w} \text{ꝟ}_1\, \Delta LENC_{\mathrm{t-i}} + \sum_{i=1}^{w} \text{ꝟ}_2\, \Delta \mathrm{LGDP}_{\mathrm{t-i}} + \sum_{i=1}^{w} \text{ꝟ}_3 \Delta \mathrm{LFDI}_{\mathrm{t-i}} + \sum_{i=1}^{w} \text{ꝟ}_4\, \Delta\, LURB_{t-i} + \sum_{i=1}^{w} \text{ꝟ}_5 \Delta \mathrm{LCOR}_{\mathrm{t-i}} + \sum_{i=1}^{w} \text{ꝟ}_6 \Delta \mathrm{LINV}_{\mathrm{t-i}} + \text{€}_t \qquad (6)$$

The absence of cointegration, which serves as the null hypothesis, is juxtaposed with the presence of cointegration, which represents the alternative hypothesis. In the event that the F-statistic surpasses the predetermined threshold values for both the upper and lower limits, it becomes untenable to embrace the null hypothesis. The null and alternative hypotheses are elegantly presented in Equations 7 and 8, respectively.

$$H_0 = \text{ꝟ}_1 = \text{ꝟ}_2 = \text{ꝟ}_3 = \text{ꝟ}_4 = \text{ꝟ}_5 = \text{ꝟ}_6 \qquad (7)$$

$$H_1 = \text{ꝟ}_1 \neq \text{ꝟ}_2 \neq \text{ꝟ}_3 \neq \text{ꝟ}_4 \neq \text{ꝟ}_5 \neq \text{ꝟ}_6 \qquad (8)$$

H_1 stands for the alternative hypothesis and H_1 for the null hypothesis.

We used the ARDL method after establishing that the parameters are co-integrated. Engle and Granger's [72] error correction model (ECM) is applied to evaluate short-term correlations and the "Error

Correction Term” after that the long-term associations have been established. Equation 9 is employed for the long-run ARDL estimation.

$$\Delta LCO_{2t} = \vartheta_0 + \sum_{i=1}^{w} \vartheta_1 \Delta \mathrm{LCO}_{2_{t-i}} + \sum_{i=1}^{w} \vartheta_2 \Delta \mathrm{LGDP}_{t-i} + \sum_{i=1}^{w} \vartheta_3 \Delta \mathrm{LPOP}_{t-i} + \sum_{i=1}^{w} \vartheta_4 \Delta\, LFDI_{t-i} + \sum_{i=1}^{w} \vartheta_5\, \Delta \mathrm{LREN}_{t-i} + \sum_{i=1}^{w} \vartheta_6 \Delta \mathrm{LFOS}_{t-i} + \ell ECT_{t-i} + €_t \qquad (9)$$

Where speed of adjustment is denoted by ℓ

3.3.3 Diagnostic Test:

This investigation employed a diverse range of diagnostic techniques to thoroughly validate the accuracy and reliability of the research findings. Within the study, various aspects of the statistical model were rigorously assessed and tested for specific issues. Heteroscedasticity, a potential concern for uneven variance in the data, was examined using the Breusch-Pagan-Godfrey test. Specification errors, which could impact model validity, were meticulously evaluated through the Ramsey Reset test. Serial correlation, a crucial consideration in time series analysis, was rigorously scrutinized using the Breusch-Godfrey LM test. To ensure that the data conforms to normal distribution assumptions, the Jarque-Bera test was applied. Moreover, the stability and reliability of the predictive model were assessed using the CUSUM & CUSUMsq test. This comprehensive battery of diagnostic tools enhances the confidence in the research results by addressing and mitigating potential statistical issues, ultimately bolstering the robustness of the study's findings.

4. Empirical Findings:

4.1 Unit Root test:

Table 02 presents the outcomes of the unit root test conducted in this study, where the Augmented Dickey-Fuller (ADF) and Phillips-Perron (P-P) unit root tests were employed to assess stationarity. The findings reveal important insights into the stationarity characteristics of the variables under investigation. Upon initial examination, it is evident that with the exception of LNENC and LNINV, all variables (specifically, LNGDP, LNFDI, LNURB, and LNCOR) did not exhibit statistical significance at the level. However, this changed when the first differences of these variables were considered, as they became statistically significant. Conversely, LNENC and LNCOR displayed significance at the level, indicating that these variables are stationary in their original form. These results suggest that LNENC and LNINV maintain their stationarity at order zero, denoted as I(0). In contrast, LNGDP, LNFDI, LNURB, and LNCOR exhibit a higher order of integration at one, or I(1), signifying that they are non-stationary at level and become stationary at their differenced forms. This observation points to a mixed order of integration among the variables, indicating that they each possess distinct stationarity characteristics. This mix of orders of integration lends support to the appropriateness of employing the Autoregressive Distributed Lag (ARDL) model in our analysis, as it can effectively handle such diverse stationarity patterns. Thus, the unit root test results not only inform our modeling approach but also underscore the importance of considering the stationarity properties of variables in time series analysis.

Table 2. Unit root test results

Variable	ADF unit root Ttst			
	Intercept		Intercept +Trend	
	Level	1st Difference	Level	1st Difference
LNENC	-2.641 (2)*	-4.762 (1)***	-1.752 (0)	-5.531 (1)***
LNGDP	-0.681 (0)	-4.084 (0)***	-1.737 (0)	-4.017 (0)**
LNFDI	-2.073 (0)	-5.275 (0)***	-2.176 (0)	-5.190 (0)***
LNURB	-0.247 (0)	-5.827 (0)***	-2.253 (0)	-5.747 (0)***
LNCOR	-2.027 (0)	-6.092 (0)***	-1.609 (0)	-6.122 (0)***
LNINV	-3.215 (0)**	-13.655 (0)***	-4.378 (0)***	-14.518 (0)***
	PP Unit root test			
Variable	Intercept		Intercept +Trend	
	Level	1st Difference	Level	1st Difference
LNENC	-6.417 (34)***	-5.908 (5)***	-1.331 (10)	-11.437 (24)***
LNGDP	-0.681 (0)	-4.011 (3)***	-1.946 (1)	-3.988 (2)**
LNFDI	-2.277 (2)	-5.275 (1)***	-2.398 (2)	-5.191 (1)***
LNURB	-0.223 (2)	-5.833 (3)***	-2.253 (0)	-5.749 (3)***
LNCOR	-1.984 (3)	-6.069 (3)***	-1.846 (3)	-6.100 (3)***
LNINV	-2.993 (3)**	-12.739 (1)***	-4.416 (3)***	-14.139 (2)***

Note: ***, ** and * denote significance at 1%, 5% and 10%, respectively.

4.2 ARDL Bound Test:

Pesaran et al. [66] employed ARDL modeling, the latest approach for assessing the co-integration relationship between the variables of interest, to investigate the long-term association between these variables. The null hypothesis of this test posits that there is no significant correlation between the variables. Rejecting the null hypothesis would indicate that there is a long-term co-integration relationship among the variables of the study. To establish co-integration and reject the null hypothesis, the test statistic's F-value should exceed the critical F-values at the upper limit. The researchers in this study utilized Eviews software to conduct the Pesaran et al (2001)'s test for evaluating co-integration in the ARDL process. The critical F-values and test statistic F-values were calculated at significance levels of 1%, 5%, and 10%. The corresponding values are presented in Table 3. The F-test statistic value of 5.301 exceeded the threshold values of 1%, 5%, and 10% for the essential f-upper value. This finding indicates that the null hypothesis is rejected, providing evidence for the presence of a long-term relationship (co-integration) among the variables examined in the initial study.

Table 3. Bound test

Lag model:		
F-statistic	5.301***	
Critical value	Lower bound	Upper bound
10%	2.26	3.35
5%	2.62	3.79
1%	3.41	4.68

Note: *** denotes significance at 1%.

4.3 ARDL Short-run and Long-run Estimation:

Table 4 presents the comprehensive long-term estimation findings derived from the ARDL model. These results offer valuable insights into the intricate relationships between key factors and energy utilization within Malaysia. Notably, the analysis reveals several significant correlations between economic indicators and energy use in the country. First and foremost, economic growth, represented by LNGDP, demonstrates a strong positive association with energy consumption. The coefficient of 0.864 suggests that a 1% increase in GDP per capita leads to an approximate 0.864% rise in energy usage. This underscores the role of economic development in driving energy demand. Similarly, Foreign Direct Investment (FDI) and urbanization exhibit notable positive impacts on energy consumption. The coefficients of LNFDI (0.070) and LNURB (0.943) indicate that a 1% increase in FDI and urbanization levels corresponds to energy consumption increases of approximately 0.070% and 0.943%, respectively. These findings highlight the role of foreign investment and urban growth in driving energy demands within Malaysia. Conversely, corruption exhibits a significant negative relationship with energy use. The coefficient of LNCOR (-1.074) suggests that a 1% increase in corruption levels results in an approximate 1.074% reduction in energy consumption. This underscores the importance of good governance and anti-corruption measures in promoting energy efficiency. Moreover, technological advancement, as represented by LNINV, positively impacts energy utilization. The coefficient of 0.139 indicates that a 1% increase in technological innovation leads to a corresponding 0.139% rise in energy consumption. This emphasizes the role of innovation in driving energy demand, potentially through the adoption of energy-intensive technologies. Therefore, the ARDL estimation results illuminate the complex interplay between various factors and energy consumption in Malaysia. Economic growth, FDI, urbanization, and technological innovation drive energy demand, while corruption acts as a deterrent. These findings offer valuable insights for policymakers and stakeholders as they formulate strategies to manage and sustainably meet the country's energy needs in the future.

Table 4. Long-run estimation results

Variable	Coefficient	Std. error	t-Statistic	Probability
LNGDP	0.864	0.132	6.519	0.000
LNFDI	0.070	0.016	4.358	0.000
LNURB	0.943	0.229	4.117	0.000
LNCOR	-1.074	0.199	-5.392	0.000
LNINV	0.139	0.045	3.067	0.006
C	-0.129	0.891	-0.145	0.885

Note: ***, ** and * denote significance at 1%, 5% and 10%, respectively

Table 5 provides a comprehensive overview of the short-term ARDL estimation results, shedding light on the dynamics of energy consumption in Malaysia. These findings reveal intriguing insights into the relationship between key variables and short-term energy usage. To begin with, the analysis demonstrates that in the short run, LNGDP, LNURB, LNCOR, and LNINV exhibit no significant relationship with energy consumption in Malaysia. This suggests that economic growth, urbanization, corruption, and technological innovation do not exert an immediate impact on energy use within the country during shorter time intervals. However, a noteworthy exception emerges in the case of Foreign Direct Investment (FDI), which displays a positive correlation with energy consumption in the short term. The coefficient of LNFDI, standing at 0.060, signifies that a 1% increase in FDI levels results in a corresponding 0.060% rise in energy consumption. This finding underscores the role of foreign investment in stimulating short-term energy demand. These short-term dynamics provide a nuanced perspective on how various factors influence energy consumption patterns in Malaysia. While some factors may exert limited influence over shorter time frames, FDI emerges as a significant driver of immediate changes in energy usage. Policymakers and stakeholders can use these insights to devise strategies that align with both short-term and long-term energy management goals for the nation.

Table 5. Shorg-run estimation results

Variable	Coefficient	Std. error	t-statistic	Prob
D(LNGDP)	-0.098	0.229	-0.428	0.673
D(LNFDI)	0.060	0.017	3.436	0.002
D(LNURB)	0.213	0.155	1.371	0.187
D(LNCOR)	-0.301	0.235	-1.281	0.216
D(LNINV)	-0.016	0.037	-0.447	0.660
D(LNINV(-1))	-0.072	0.023	-3.101	0.006
D(LNINV(-2))	-0.074	0.016	-4.456	0.000
D(LNINV(-3))	-0.069	0.015	-4.385	0.000
CointEq(-1)	-0.868	0.156	-5.559	0.000

Note: ***, ** and * denote significance at 1%, 5% and 10%, respectively

4.4 Diagnostic Test results:

As illustrated in Table 6, the methodology employed in this study has undergone rigorous diagnostic scrutiny, revealing its robustness in handling potential statistical issues. Notably, the analysis indicates an absence of concerns related to serial correlation, non-normality, or heteroskedasticity, bolstering the reliability of the model. Additionally, the Ramsey RESET test offers assurance that there are no missing variables within our meticulously constructed model, affirming its completeness. Further reinforcing the model's stability and predictive power are the results of the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) stability tests, depicted graphically in Figure 2. These plots, firmly positioned within the 5% significance threshold, provide compelling evidence of the model's consistency and reliability over time.

Table 6. Diagnostic tests results

Test statistic	F-statistic	Probability

Breusch-Godfrey SerialCorrelation LM	1.465	0.260
Ramsey RESETstability	1.344	0.262
Heteroscedasticity	1.133	0.394
Jarque-Bera	7.138**	0.028

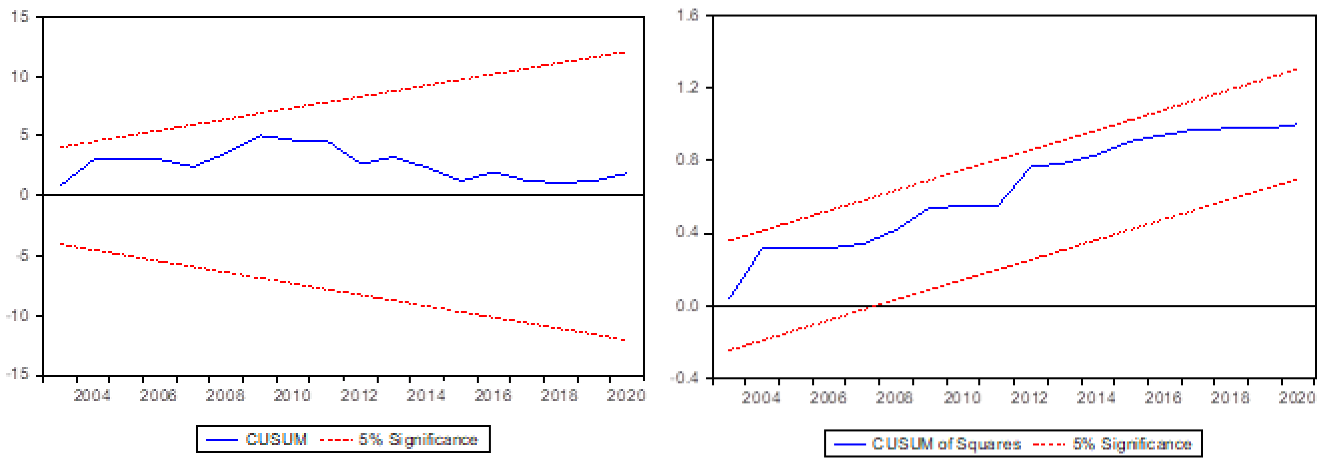

Figure 2: CUSUM and CUSUMSQ test

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